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# Investigating the Effects of Roadway Design on Driver Behavior: Applications for Minnesota Highway System

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# **Investigating the Effects of Roadway Design on Driver Behavior: Applications for Minnesota Highway Design**

## **Final Report**

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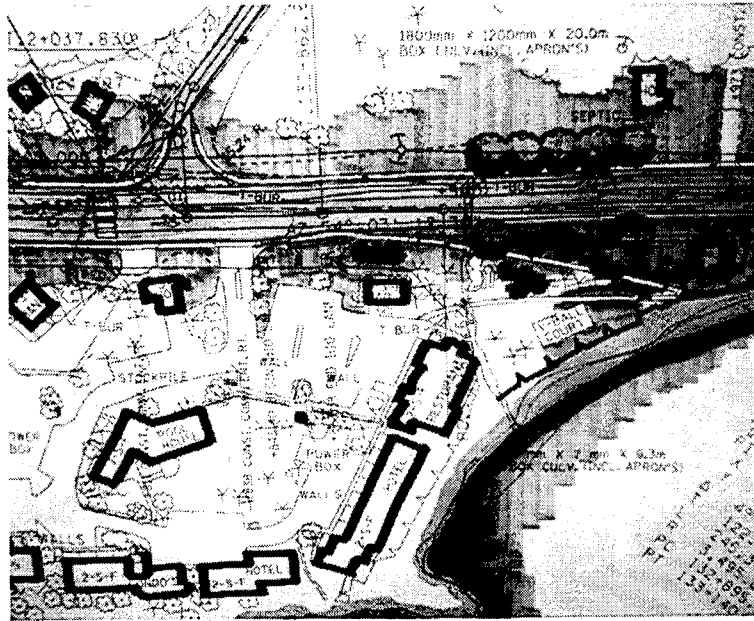
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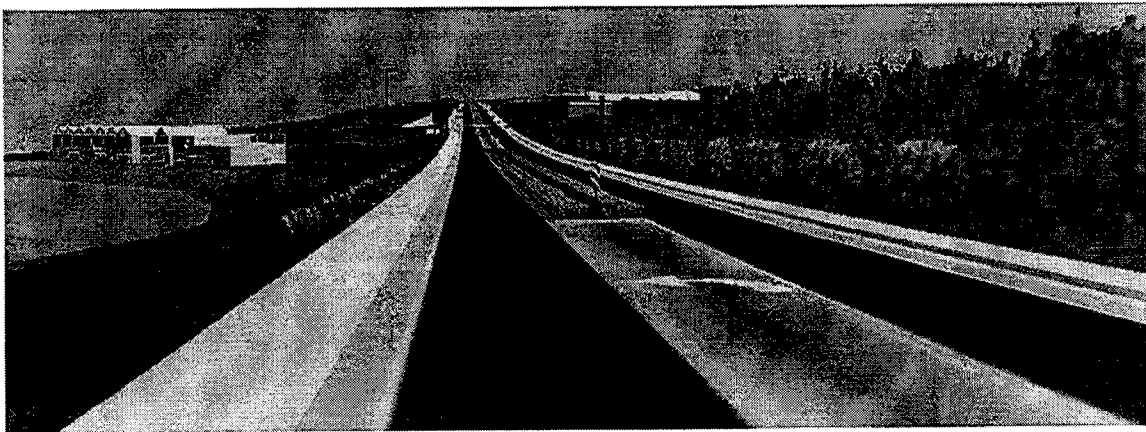
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**PLANNING**



**VISUALIZATION**



**EXPERIMENTATION**





## **ACKNOWLEDGEMENTS**

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## EXECUTIVE SUMMARY

This report details a project to study the relationship between highway design and human behavior as influenced by roadside environments. The project was developed in two phases. In the visualization phase, computer simulation was used to model an actual segment of urban highway planned for reconstruction in Tofte, Minnesota. Using a driving simulator, project design team members could test drive the highway reconstruction project and evaluate the planned elements. In the experimentation phase, drivers' responses to different design scenarios were tested, so that architectural and aesthetic elements having the greatest potential for calming or slowing traffic could be identified. Results from the visualization phase indicated increased communication among project team members and state agencies. Interactive visualization also facilitated problem identification, resolution strategy development, and decision making concerning potential design options and design elements. Results from the experimentation phase indicated that white pavement treatments produced more moderate speeds and larger speed change, a desirable traffic calming effect. Data also indicated that landscape architecture treatments on the medians and road edges can also produce desirable effects in drivers' choice of speeds, although effects were inconsistent. The presence of lighting poles did not contribute to traffic calming. Analyses of drivers' speed and speed change patterns also indicated a consistent speed profile, characterized by marked decrease in speed until the third island, after which speed increased steadily. The report concludes with recommendations for the expanded use of visualization in general, and the implementation of white pavement treatments in the target reconstruction project specifically. Landscape architecture treatments were also recommended for further consideration.



## INTRODUCTION

There are a number of roadway settings where drivers must adjust their speed and alignment in response to changing driving environments. These places often represent the locations where the greatest safety hazards and accident rates occur. One example is a town located on a trunk highway, where drivers are required to reduce speed as they transition from higher travel speeds in rural environments to lower travel speeds in urban environments. Normally, road signs are used as the main visual information to influence the driver. However, the elements of the roadway environment (e.g., paving materials, furniture and fixtures, signs and markings, color, planting, lighting, etc.) also give visual cues about speed and alignment.

This report details a visualization and research project designed and coordinated by the Human Factors Research Laboratory (HFRL), University of Minnesota, in association with the Minnesota Department of Transportation (Mn/DOT) to study the relationship between highway design and human behavior as influenced by roadside environments. This project used a wrap-around driving simulator developed by the Human Factors Research Laboratory to test driver responses to roadside patterns and environments. Computer simulation was used to model an actual segment of urban highway (TH 61) planned for reconstruction in Tofte, Minnesota. Models were then loaded into a driving simulator and driver performance was monitored in a controlled experiment. The experiment tested various roadway design options developed by Mn/DOT to reduce the negative impact of car traffic on the municipality with an emphasis on speed reduction and urban space enhancement.

The project was developed in two phases. In the first phase (visualization), an interactive and representative driving simulation of the planned highway construction was developed. Project design team members could test drive the highway reconstruction project and evaluate the planned elements. Additional test drive scenarios were also developed, representing potential design changes. In the second phase (experimentation), drivers' responses to different design scenarios were tested, so that architectural and aesthetic elements having the greatest potential for calming or slowing traffic could be identified. Thus, the conclusions of this report address the relationship between highway engineering, behavioral science and aesthetic design, and how

attention to pleasing aesthetic solutions, together with functional and economic considerations, can satisfy the broader requirement of promoting greater highway safety and improving quality of life.

These highway visualization and experimentation initiatives represent the first use of the HFRL driving simulator as part of the Mn/DOT highway design process, thereby allowing designers to visualize the project and 'test drive' various design options before completing plans and construction documents. The project is a significant undertaking because the highway design solutions tested were themselves both innovative and experimental. As Mn/DOT designers learned more about their specific project, University researchers broadened and refined their skills and research methods created by engaging in the study process. Ultimately, both Mn/DOT and the University will validate the research and development process by participating in a field test which is planned following completion of the actual highway construction project.

## **PROJECT TEAM**

### **Mn/DOT Project Design Team**

Rod Garver – TH61 Corridor Manager  
Pat Huston – Project Design Engineer  
Duane Hill – Project Development Engineer  
Dave Pickett – District Traffic Engineer  
Gary Mueller – Project Landscape Architect

### **Mn/DOT Project Oversight Team**

James Reiersen – Site Development Unit Manager  
Dennis Moline – Visualization Unit Manager  
Ronald Casellius – Research Program Administrator

### **University of Minnesota Visualization and Experimentation Development Team**

John Carmody, College of Architecture & Landscape Architecture  
Steve Scallen, Director of Research Operations, Human Factors Research Laboratory  
Jim Klinge, Laboratory Engineer, Human Factors Research Laboratory

Peter Easterlund, Real-Time 3D Applications Developer, Human Factors Research  
Laboratory

Janelle Monette, Graduate student, Human Factors Research Laboratory

## **HIGHWAY PROJECT DESCRIPTION**

To facilitate the vision of a safer Lake Superior North Shore Highway 61 route, the Minnesota Department of Transportation (Mn/DOT) has prepared a comprehensive development plan, which is now in various stages of refinement and implementation. This plan, which carefully and respectfully guides more than \$66 million of highway improvement investment, addresses both highway safety and roadside aesthetics, consistent with the needs and expectations of the highway users and the communities through which the road passes. One such community, which is also at the center of this research project, is Tofte, Minnesota.

Both existing and proposed trunk highway 61 (TH61) bisect the municipality of Tofte, which is centrally located within an 80 mile stretch of road regarded as the key economic and social lifeline connecting Minnesota's arrowhead region with the rest of the state, nation and Canada. Like most other cities and towns located along this route, Tofte developed largely because of the presence of the trunk highway, although development occurred in the absence of a strong planning focus, a situation that both Mn/DOT and Tofte were anxious to change.

At meetings hosted by Mn/DOT, the local community voiced its desire for safe roads, especially with respect to the high rates of speed for pass-through traffic. Residents were also concerned about the effect that the proposed highway project would have on the community, or rather, the loss of community. Like many other communities, including those along this highway route, the citizens of Tofte wanted to protect their unique, vibrant community from the permanent destruction of highway expansion and the invasive behavior of traffic which long has dominated this route. Thus, the local community expressed a desire to explore all options and techniques related to slowing pass-through traffic, collectively known as 'traffic calming'.

Traffic calming is a form of traffic planning that seeks to equalize the use of streets and roads among automobiles, pedestrians, bicyclists and playing children. Traffic calming is achieved through the use of devices and techniques that reduce traffic volume and speed while maintaining mobility and access. It is so new and antithetical to traditional thinking and planning that the techniques invite a certain amount of skepticism. In order to successfully implement traffic calming in a community, planners and engineers must look at the transportation system as a whole within the area or community affected. Thus, a focus on traffic calming provides opportunities to examine other highway design related issues that will have affect on the quality of life in a community. While traffic calming and context-sensitive planning approaches are becoming more widely accepted within planning and resident communities, traffic calming in a rural setting like the TH61 Highway Corridor is unique and will qualify the proposed highway redevelopment project as an important pilot project in the United States.

Among the design changes proposed for two-lane rural segments of the TH61 highway corridor are wide shoulders and adequate ditching added to provide for safe pullover and maneuver space and control highway drainage. In the urban segment of the route, through towns like Tofte where lower traffic speeds are required, a center turn lane and crosswalks will be added and narrower shoulders, curb and gutter and sidewalks will replace the wide shoulders and ditches. While the changes of the urban section are intended to improve traffic flow and increase safety, they also will change the psychological feel of the road. Alone, wide and straight stretches of paved roads say to a motorist, "Speed up. Drive faster". However, roads that look more like city streets, use paved strips or narrowed lanes and include furniture and landscaping, have a relaxed, pedestrian feel that say to the driver, "Slow down and beware, this is shared space." Properly implemented, traffic calming techniques can use the physical environment to alter the ways that drivers and all other users of the road 'experience' the route. Most importantly, drivers recognize the street or road as a shared place that has an identity or character, rather than as a channel designed for the singular focus of the automobile.

To accomplish the objective of reducing traffic speeds through Tofte while preserving and improving a sense of community, Mn/DOT landscape architects proposed a context-sensitive Design Opportunities Plan recommending both traditional and non-traditional design treatments

and features. Among the traditional treatments were traffic medians with landscaping designed to create a gateway effect at the city entrances. The gateways were to be heavily planted with trees in a non-traditional way, to create a narrowing effect of the roadway environment. Another strategy involved the use of colored asphalt paving (using white rock in the bituminous mixture) to create the illusion of paved strips and/or narrowed lanes. While colored asphalt paving itself is not new, the intentional use of colored pavement to slow traffic represents a newly developed traffic calming strategy.

Because many of the ideas in the Design Opportunities Plan were based on new and cutting-edge philosophies, some of which had not yet been tested or implemented, Mn/DOT wanted demonstrated assurances for success prior to actual implementation. As a first step, Mn/DOT desired an opportunity to visualize the design proposal, including all planned applications and traffic calming measures. In addition to general questions concerning the effectiveness of traffic calming measures, the Project Design Team had a number of specific concerns about design elements of the proposed traffic calming plan, including:

- What effect will colored bituminous pavement have on driver behavior? Specifically, will white pavement contribute to speed reduction?
- What effect will median landscape treatments have on driver behavior? Specifically, will shrubs and bushes on the median and road edge contribute to speed reduction?
- What effect will vertical element have on driver behavior? Specifically, will lighting poles or trees placed at or near to the edge of the road contribute to speed reduction?
- Are any specific design measures more or less effective than others?
- What is the minimum degree of presence required for effectiveness?
- Are various designed elements too subtle to be noticed by drivers?

Answers to these questions framed the basis of the experimental effort.

## **RESEARCH PROJECT**

The MN/DOT project team approached the Human Factors Research Laboratory, University of Minnesota, to explore questions about the potential effectiveness of the Design Opportunities Plan. John Carmody and Steve Scallen at the University had received a Mn/DOT grant through the Center for Transportation Studies, which was intended to assist Mn/DOT in exploring these kinds of problems. The Human Factors Research Laboratory provided the facility for studying these questions.

The project team worked with the University team to develop experimentation concerning the effectiveness of the proposed design. The 3 km urban section of Highway 61 through Tofte, Minnesota was selected for testing. Using the wrap-around driving simulator at HFRL, a computer model of the roadway was created and the effect of different design features on driver behavior were tested.

In the early development of the project, it became apparent that the interactive model, in conjunction with HFRL's driving simulators served two unique functions. First, as a visualization tool that enabled the team to better understand their design and communicate with each other about potential problems and design alternatives. Second, as a tool for testing driver behavior and predicting the effectiveness of different elements of the design. This dual role of the project, as a visualization tool and as an experimental test platform, is reflected throughout this report.

## **PROJECT PURPOSE AND GOALS**

### **Visualization**

The purpose of visualization is for the project team to envision the design options in a realistic computer simulation. General goals of the visualization are to facilitate increased communication among team members, contribute to efficient decision making on all aspects of project development, and to identify problems and issues and develop resolution strategies. Specific goals for the visualization initiative are:



- To develop a realistic interactive three-dimensional model of the planned construction project including roadway features, elevation features, and environmental features (e.g., local buildings)
- To provide team members opportunities to interact (drive) with the planned design and develop design alternatives based on the interactions.
- To provide rapid prototyping of potential design changes.

### Experimentation

The purpose of experimentation is to quantify driver responses to the planned design in general and to particular design elements specifically (pavement treatment, landscape treatment, and lighting treatment). Particular emphasis is on the identification of potential design elements that will contribute to reduced and moderate driver speeds. General goals of the experimentation initiative are to identify design elements that contribute to safe driver behaviors, contribute to the selection of design elements to be included in the final design, and to explore the potential of human factors experimentation to contribute to highway design. Specific goals for the experimentation initiative are:

- To evaluate driver responses to presence of landscape treatments proximate to the roadway, specifically the presence of shrubs on the medians and shoulders.
- To evaluate driver responses to presence of pavement treatments on the roadway, specifically the presence lighter colored pavement in the center turn lane and shoulders.
- To evaluate driver responses to presence of lighting treatments proximate to the roadway, specifically the presence lighting poles at regular intervals along the roadway.



## METHODS

### VISUALIZATION

The project team selected the urban section at Tofte, Minnesota because it is an upcoming project with design features common to many other two lane roads passing through towns. The Mn/DOT Highway 61 corridor team in Duluth had developed the design to the point where road alignment and profiles were set. The Mn/DOT landscape architects in St. Paul had developed a design for Tofte that included traffic calming features.

The University team met with the Highway 61 corridor team and the landscape designers to clarify the design and create a computer model of the Tofte section of the highway. Developers at the Human Factors Research Laboratory used architectural design, engineering cross-sections of the Tofte area (detailing elevation changes), and photo surveys of area terrain and landmark structures to develop an initial three-dimensional model of the project. The team regularly reconvened to view and revise the computer simulation. This process was repeated several times until the model was a satisfactory representation of the roadway and surrounding environment.

This iterative process was not simply a means of making the roadway more realistic and faithful to the original design. It was also a design and communication tool for the team to evaluate their design intent, make assessments of their decisions, and make modifications to the original design. Several versions of the model were developed, representing a wide array of potential designs.

Once the team refined the model to a satisfactory level, the team selected the main traffic calming design features they wanted to evaluate. There were two overriding principles in selecting the scenarios. First, there must be a limited number of variables (2 or 3) resulting in 4 to 8 total scenarios. This is necessary to ensure that a single subject can drive a complete set of scenarios. Second, the design features selected for testing should represent significant, rather than subtle, variations. For example, in these initial rounds of testing, it was most efficient and useful to compare the presence or absence of trees and shrubs by the roadway rather than compare the size and shape of the shrubs. If there is any effect at all from trees and shrubs, then

more detailed evaluations can follow. The team selected the following main variables to be tested in the Tofte urban section:

- The presence of white-colored asphalt (see Figure 1) in the center left turn lane and shoulders. Black color is standard (see Figure 2)
- The presence of shrubs (see Figure 3) on the median and close to the road edge at the town entrances and crosswalks. No landscape elements are standard (see Figure 4)
- The presence of light poles on both sides of the roadway (see Figure 5). The alternate is no poles (see Figure 6)

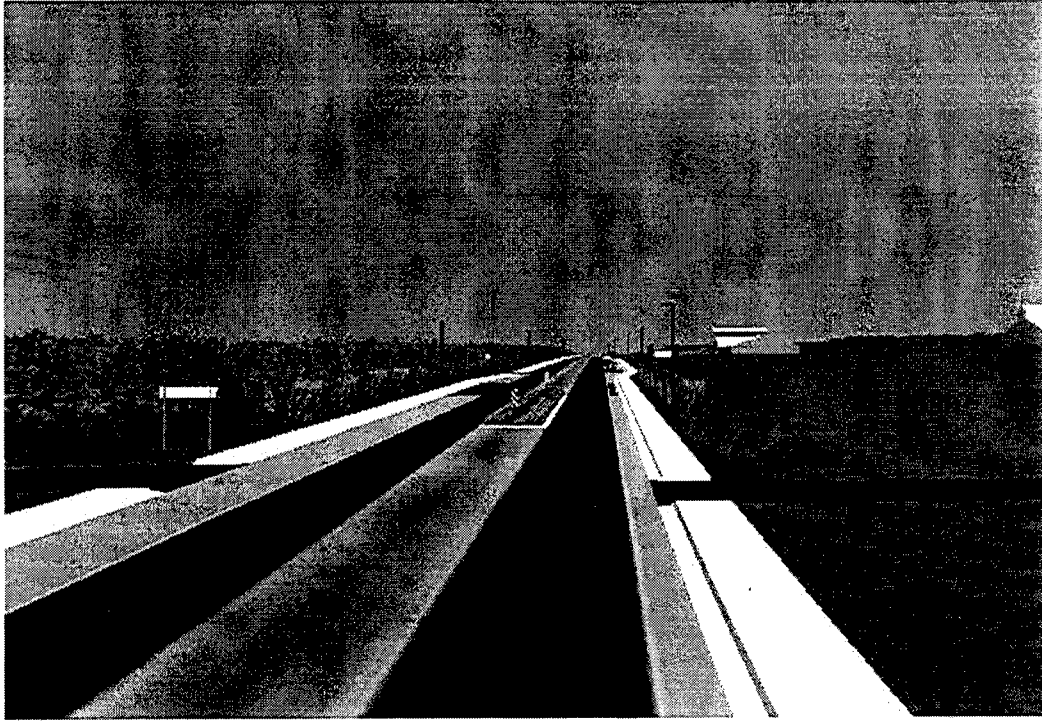


Figure 1. White road treatments on the median, center left-turn lane, and shoulders.

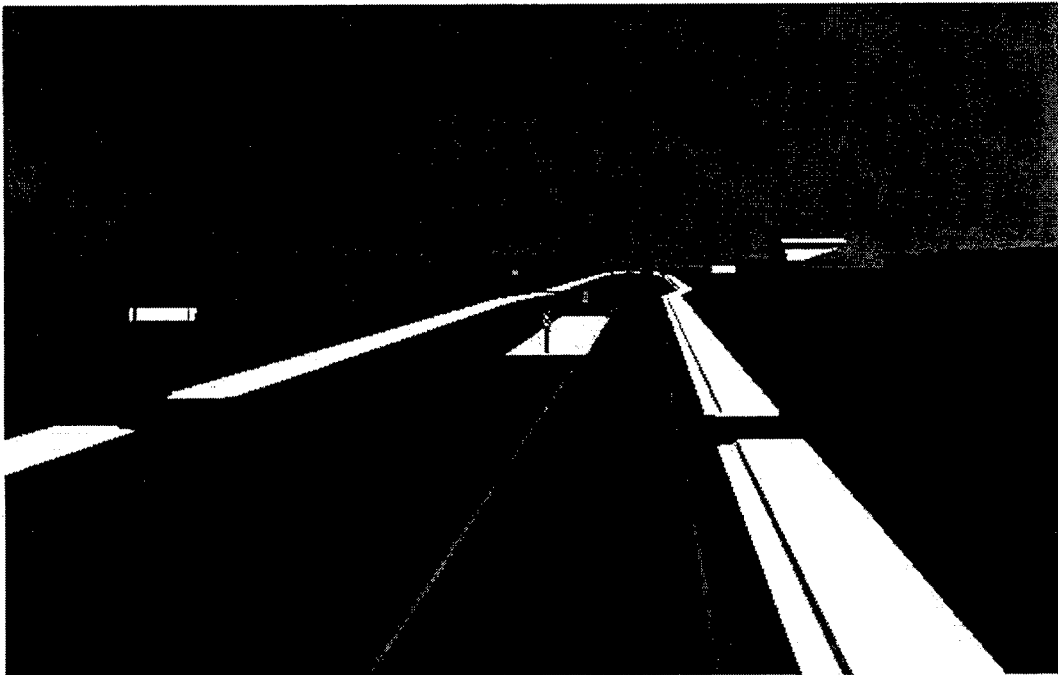


Figure 2. Standard black road treatment.



Figure 3. Landscape treatments on the median and road edge.

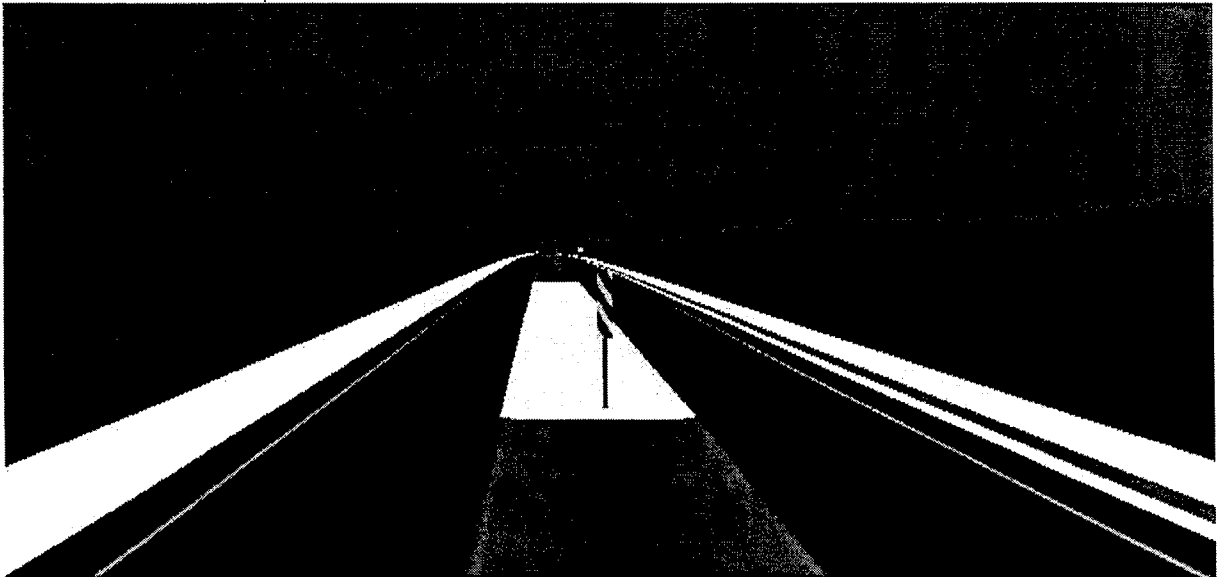


Figure 4. Standard no-landscape treatments on the median and road edge.

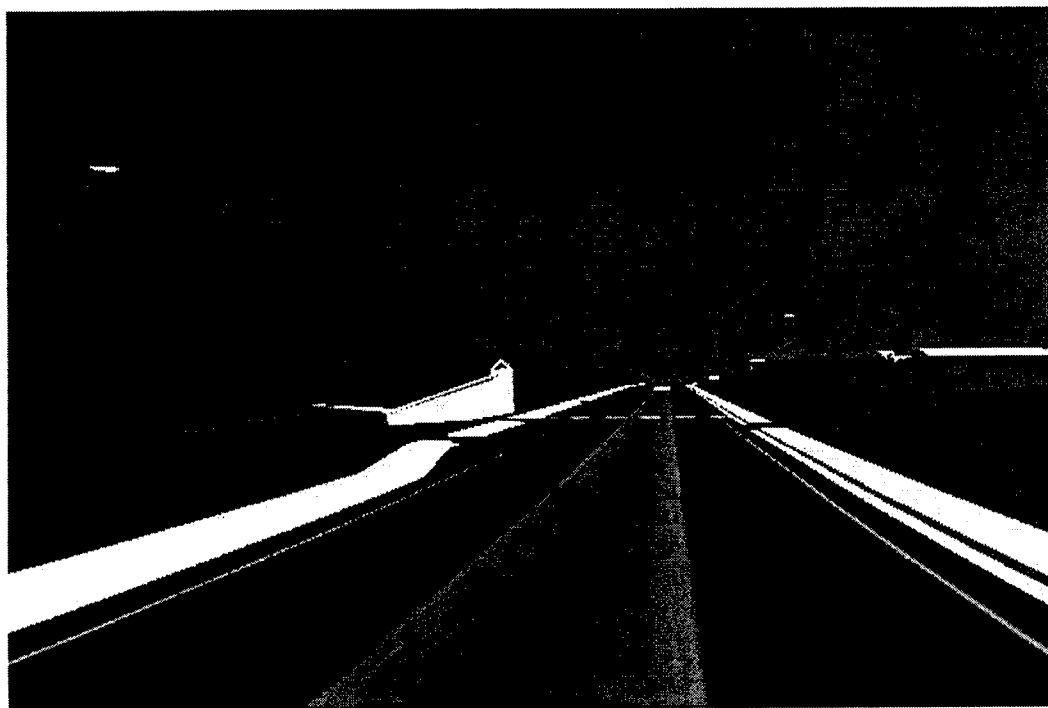


Figure 5. City design with lighting treatments.

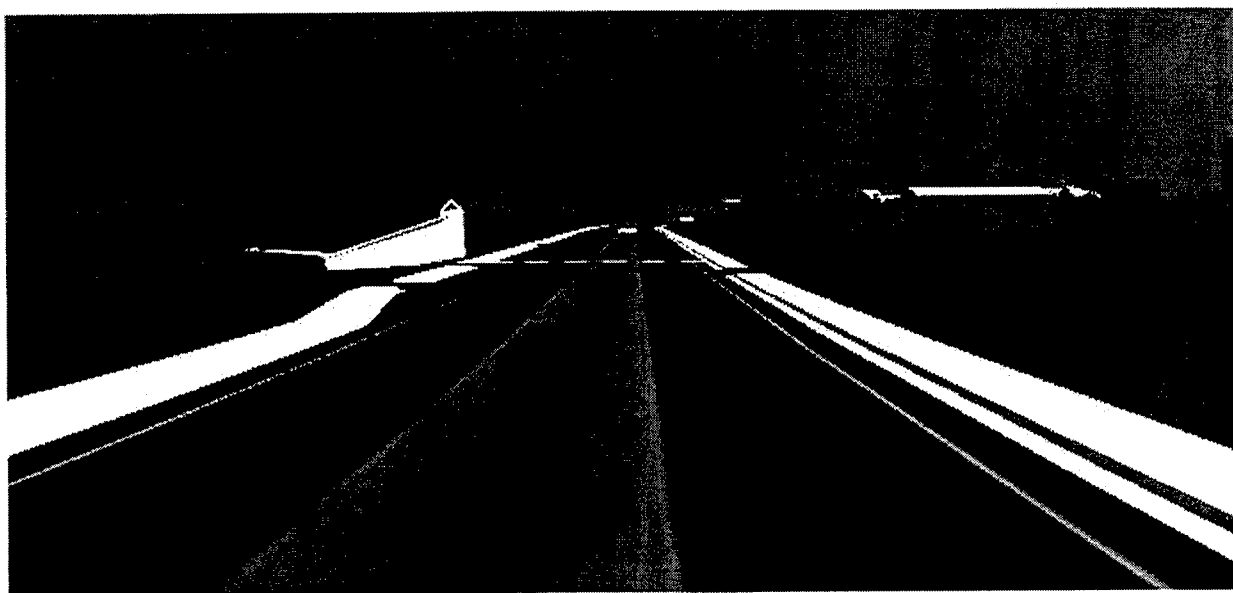


Figure 6. City design with no lighting treatments.

## EXPERIMENTATION

### Scenario Development

Factorial combination of the three factors of interest produced eight potential design scenarios, see Table 1.

Table 1. Possible Design Scenarios

1. Lighting poles-black pavement-shrubs
2. Lighting poles-black pavement-no shrubs
3. Lighting poles-color pavement- shrubs
4. Lighting poles-color pavement-no shrubs
5. No lighting poles-black pavement- shrubs
6. No lighting poles-black pavement-no shrubs
7. No lighting poles-color pavement- shrubs
8. No lighting poles color pavement-no shrubs

An interactive driving simulation was developed for each of the eight scenarios. Each scenario began with a three kilometer highway drive, consisting of a two-lane bi-directional road with gradual left and right curves. This three kilometer highway section was identical for each scenario.

### Apparatus

The interactive driving scenarios were displayed in the Human Factors Laboratory's wrap-around driving simulator (WAS). The WAS is a high-fidelity driving simulator that allows for a 360 degree viewing area to immerse the subject in a virtual driving environment. The simulator is a spherical steel and wooden dome structure with eight white fiberglass screens. Each screen extends from the floor to a height of 250 cm. Individual screens are synthesized with adjacent screens making a single screen wrapping 360° around the driver and vehicle. Driving scenes are programmed with SGI Performer Graphics Libraries, displayed with a SGI Onyx computer (Reality Engine 2) and projected through four Electrohome ECP-3100® projectors. Three



forward projections are synthesized so they appear as one single image subtending a 180° field of view horizontally and a 55° field of view vertically. One rear projection subtends 55° field of view horizontal and 55° field of view vertically. A full-sized 1990 Acura Integra RS is equipped with sensors for gas, brake, and steering control, facilitating real-time driver input. A torque motor attached to the steering wheel provides steering force feedback.

### Research Participants

Participants were licensed drivers in the state of Minnesota. Sixteen (16) males and sixteen (16) females volunteered to participate for the study. Detailed demographics and driving experience are detailed in Table 2. All subjects had normal, or corrected to normal vision. Subjects were given \$10 for participating in the hour-long experimental session.

Table 2. Subject Demographics and Driving Experience

	Mean Age:	Range
Total (32)	27.4 years	19-57 years
Males (16)	24.2 years	19-34 years
Females (16)	30.6 years	19-57 years
How often do you drive? (Very Frequently-1 to Almost Never-5)		1.5
How much of your driving occurs on city streets? (All-1 to None-5)		2.2
How much of your driving occurs on rural country roads? (All-1 to None-5)		3.8
How much of your driving occurs on highways (All-1 to None-5)		2.3
How often do you KNOW the posted speed limit? (Always-1 to Never-5)		2.0
How often do you KNOWINGLY drive faster than the posted speed limit (Always-1 to Never-5)		2.1

### Procedure

Pilot testing prior to the implementation of data collection indicated significant fatigue and motivation effects when subjects drove all eight design scenarios. In order to reduce the number of experimental scenarios from eight to four, the lighting treatment factor was assigned as a between subjects factor. Half the male and half the female participants drove scenarios with

either lighting poles present or lighting poles not present. Subject assignment to conditions was randomized.

All subjects signed an informed consent and received practice-to-criteria training on the simulator controls. All subjects had to demonstrate control of vehicle speed, steering, and lane control in a practice driving scenario. Subsequent to training subjects were instructed to memorize a random seven-digit number. Subjects then received the following instructions:

*Please drive through the scenario completely in the right hand lane at a speed such that you feel safe and in complete control of the vehicle. You are free to drive at any speed that you feel safe and comfortable. You may also change your speed at any time, the speedometer reflects your actual speed. As you drive through the scenario please pay attention to the scene in front of you, as the scenery will change throughout the drive. We will be asking questions about the scenery at the end of the session.*

Subjects then drove four scenarios. Each scenario was a southbound drive. At the end of each scenario subjects performed a number recognition task involving the memorized seven-digit number. Subsequent to the number recognition task, a new scenario was loaded into the simulator and instructions were repeated. This process was repeated until the subject completed all four scenarios. Order of scenarios was counterbalanced across subjects such that scenarios were equally represented in each order position. The number recognition task served was not relevant to the experimental goals and served only to distract the subject during scenario intervals and ensure cognitive stimulation during experimental procedures. Subsequent to data collection, each subject completed a debrief questionnaire.

### Dependent Measures

Vehicle speed, vehicle position in the lane, accelerator actuation, and brake actuation were collected every second (1Hz) of the experimental drives. Only data for the 'city' portion of the scenarios were included in the analyses, where 'city' is defined as a point 1000 meters prior to the welcome sign, continuing for 3600 meters to the exit sign. These measures yielded the following derived measures of performance and behavior for data analyses: speed (major measure of interest), speed variability (measure of performance consistency), speed change over a specific

distance (target behavior of interest), lane position variability (measure of lateral control), accelerator actuation variability (measure of active participation), and brake actuation variability (measure of active participation).

Computation of data for analyses was conducted via two procedures:

Procedure 1: Global city measures reflect general performance behavior, averaged through the entire city (welcome sign to exit sign). The following measures were computed for analyses:

- Average speed – average of all speed data from welcome to exit sign
- Speed variability – variability of all speed data from welcome to exit sign
- Average speed change – the speed of the vehicle at the welcome sign is subtracted from each subsequent data point until the exit from the city. The resulting points are then averaged.
- Lane variability – variability of all lane position measurements from welcome sign to exit sign.
- Accelerator actuation variability – variability of all accelerator data from welcome sign to exit sign
- Brake actuation variability - variability of all brake data from welcome sign to exit sign.

Procedure 2: Measures-at-point reflect performance and behavior at specific points in the scenario. Vehicle speed, lane position, accelerator and brake actuation were collected at 15 specific measurement points, see Table 3.

Table 3. Measurement Points

Measurement Point	Geographic Marker	Distance from entry (welcome sign)	Distance to exit (exit sign)
1		(-) 1000 m	3600 m
2	welcome sign	0 m	2600 m
3	start of 1st island	169 m	2431 m
4	end of 1st island	206 m	2394 m
5	start of 2nd island	490 m	2110 m
6	end of 2nd island	621 m	1979 m
7	start of 3rd island	962 m	1638 m
8	end of 3rd island	1009 m	1591 m
9	start of 4th island	1337 m	1263 m
10	end of 4th island	1402 m	1198 m
11	start of 5th island	1788 m	812 m
12	end of 5th island	1835 m	765 m
13	start of 6th island	2348 m	252 m
14	end of 6th island	2376 m	224 m
15	exit sign	2600 m	0 m

The derived at-point measures are:

- At-point speed – vehicle speed at each measurement point
- Speed change – the speed of the vehicle at measurement point 1 (1000 m before the welcome sign) is subtracted from each subsequent measurement point

#### Experimental Data Analyses

Global measures will be subjected to mixed model between (SEX, lighting POLE) – within (SHRUB, PAVement marking) Analysis of Variance (ANOVAs) with each global measure serving as the dependant variable. These analyses are designed to reflect general/average performance in the city.

At-point measures will be subjected to mixed model between (SEX, lighting POLE) – within (SHRUBS, PAVement marking, measurement POINT) ANOVAS with measurement points serving as the dependant variables. These analyses are designed to reflect changes in speed through the city. Speed change analyses also control for variability introduced between drivers by allowing subjects to select their own rate of speed.

Unless otherwise stated, reported degrees of freedom and probabilities for repeated measures effects and associated interactions were adjusted based on the Greenhouse-Geisser epsilon when deemed necessary by a significant Mauchly sphericity statistic. Where appropriate, follow-up tests were conducted using the Tukey comparison, unless otherwise indicated. A traditional level of significance ( $p < .05$ ) is adopted for all parametric testing. Results will not be presented for four-way interactions due to the complexity of interpretation.



## **RESULTS**

### **VISUALIZATION**

The results of the team meeting and development of the scenarios on the driving simulator are as follows:

- The communication about proposed design options was improved between the corridor team in Duluth and the landscape architects in St. Paul.
- The design was modified and refined in a number of ways based on the ability to see and drive through the simulation at actual speeds.
- Multiple versions of the model were developed, representing different combinations of potential design factors
- There are limitations to the degree of realism and detail that can be produced on the driving simulator.

### **EXPERIMENTATION**

#### **Global Measures Analyses**

Global measures of average speed, speed variability, speed change, lane variability and accelerator variability were calculated and subjected to the designed analyses. (Brake actuation variability was removed from all analyses when it was determined that only 2 of 32 subjects ever used the brake). Analyses indicated only speed change was sensitive to experimental manipulations, revealing a PAVE X POLE interaction ( $F(1,28)=6,64$ ,  $p<.05$ , see Figure 7).

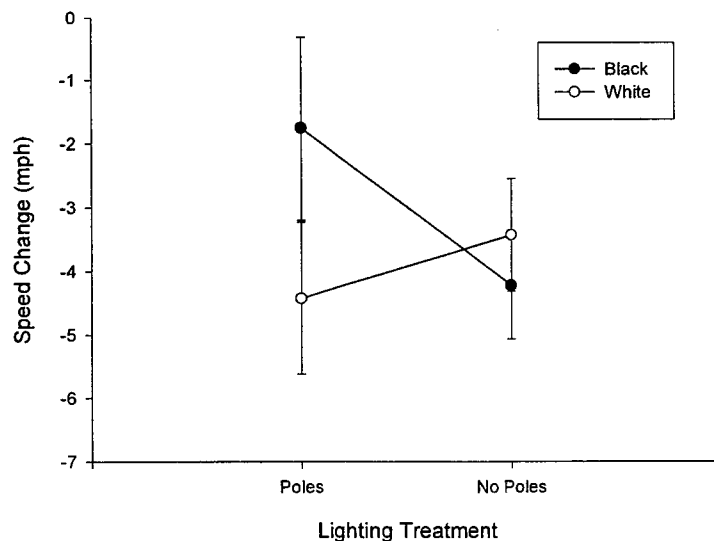


Figure 7. Average speed change as a function of pavement and lighting treatments.

#### At-Point Analyses – All Measurement Points

At point measures of speed and speed change were calculated and subjected to the designed analyses. Both speed and speed change indicated main effects for measurement POINT ( $F(14,392)=28.84$ ,  $p<.05$  and  $F(13,364)=30.77$ ,  $P<.05$ ), respectively). Data are presented in Figures 8 and 9. Further analyses was halted after it was determined that the large number of measurement points may contribute to spurious interaction effects.

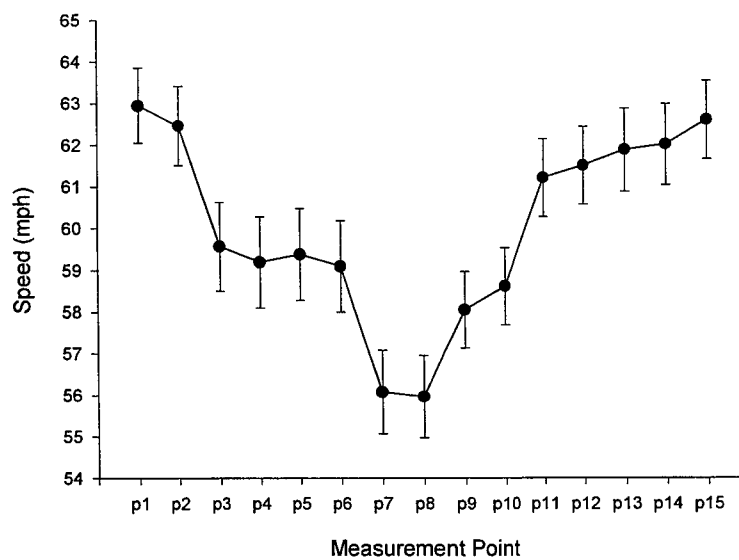


Figure 8. Drivers' speed at 15 measurement points.



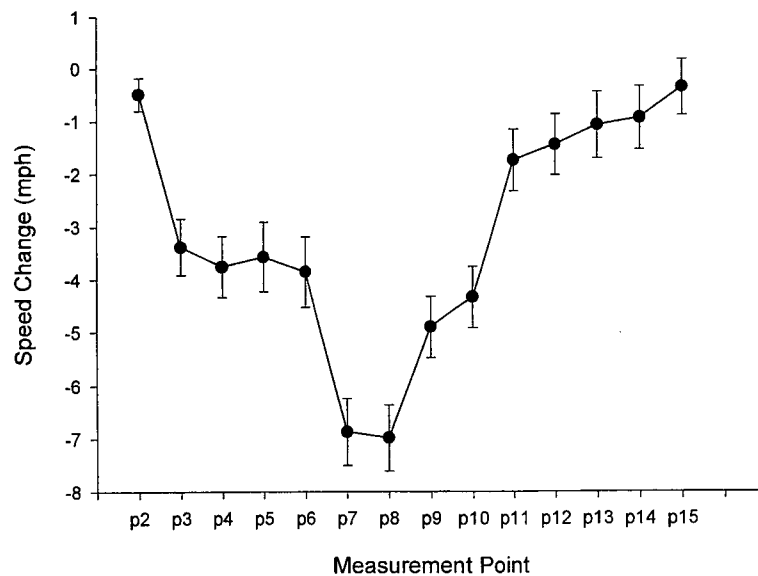


Figure 9. Drivers' speed change at 14 measurement points.

#### At-Point Analyses – Modified Measurement Point Set

Due to the potential for spurious interactions, the original data set of 15 measurement points was reduced to 6 measurement points, see Table 4. Planned analyses were conducted on this reduced data set.

Table 4. Reduced Set of Measurement Points

1. 1000 m before the welcome sign (approximately 3600 meters from 0 point)
2. welcome sign (approximately 2600 meters from 0 point)
6. end of the second island (approximately 1979 meters from 0 point)
8. end of the third island (approximately 1591 meters from 0 point)
12. end of the fifth island (approximately 765 meters from 0 point)
15. exit (approximately 0 meters from 0 point)

Analyses for speed indicated a main effect for measurement POINT ( $F(5,140)=29.15$ ,  $p<.01$ , not shown) and PAVE X POINTS ( $F(5,140)=2.401$ ,  $p<.05$ , see Figure 10) and PAVE X POINTS X POLE ( $F(5,140)=2.294$ ,  $p<.05$ , not shown) interactions. Analyses for speed change indicated a

main effect for measurement POINT ( $F(4,112)=39.57$ ,  $p<.01$ , not shown) and PAVE X POINT ( $F(4,112)=2,509$ ,  $p<.05$ , see Figure 11) and PAVE X POINT X POLE ( $F(4,112)=21.56$ ,  $P<.05$ , see Figure 12) interactions.

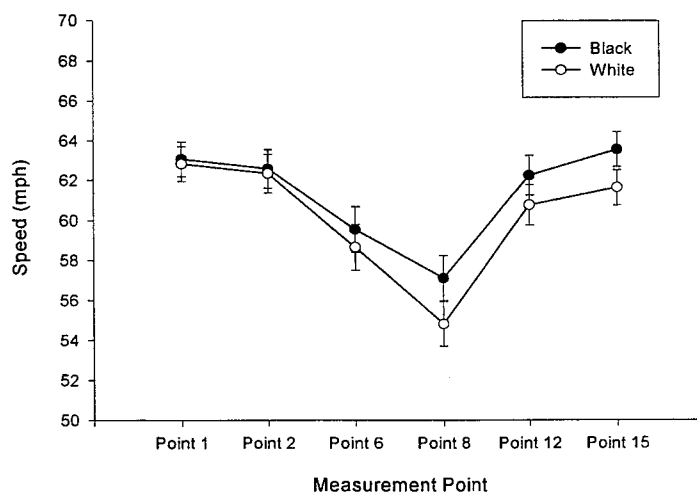


Figure 10. Drivers' speed as a function of pavement treatments and measurement points.

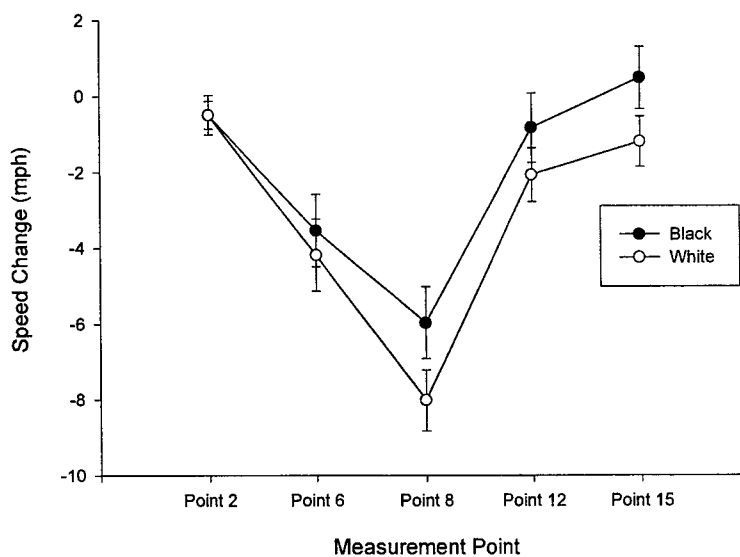


Figure 11. Drivers' speed change as a function of pavement treatments and measurement points.

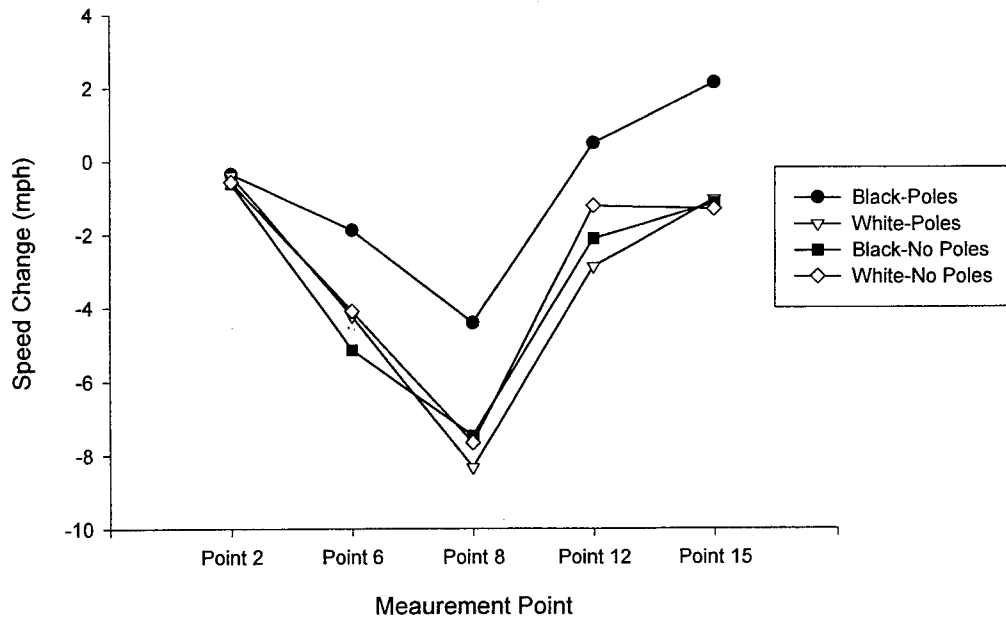


Figure 12. Drivers' speed change as a function of pavement treatments, lighting treatments, and measurement points.

#### Post-Hoc Analyses

Subjective debrief sessions and subjective debrief questionnaires identified possible confounding effects associated with the condition orders. Despite extensive training, some participants reported learning effects in early trials, while others reported fatigue or boredom in later trials. To test effects associated with trial order, each of the 5 global measures were subjected to a mixed model in which trial order was a within subject variable and lighting poles and sex were between subjects variables. Average speed ( $F(3,84)=12.753, p<.01$ , see Figure 13), speed variability ( $F(3,84)=8.226, p<.01$ , see Figure 14) and accelerator variability ( $F(3,84)=3.9966, p<.05$ , see Figure 15) demonstrated a significant order effects. No other main effects or interactions were significant.

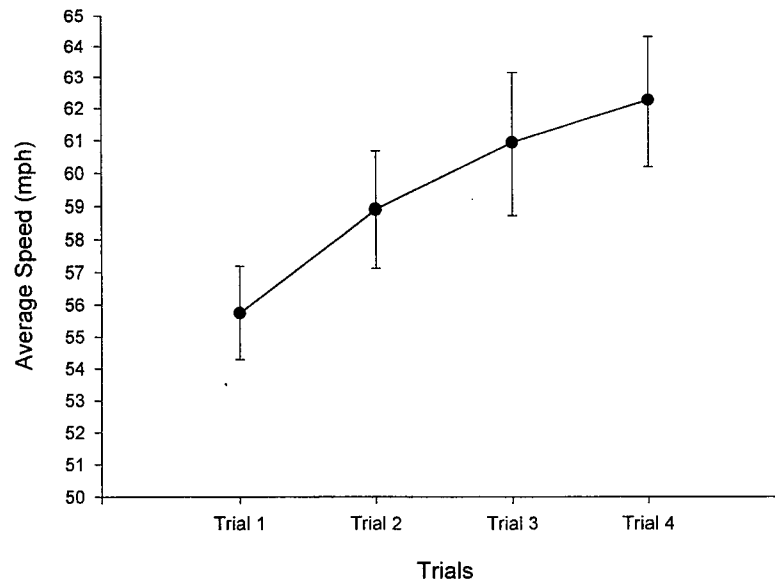


Figure 13. Drivers' average speed as a function of trial order.

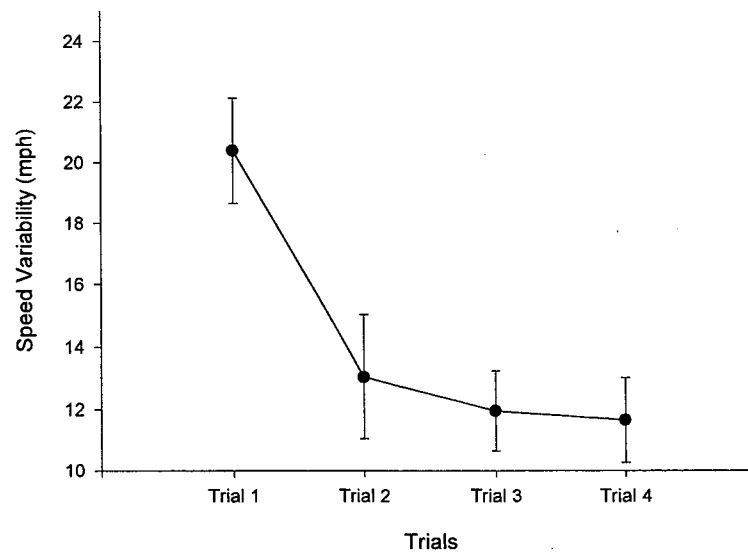


Figure 14. Drivers' speed variability as a function of trial order.

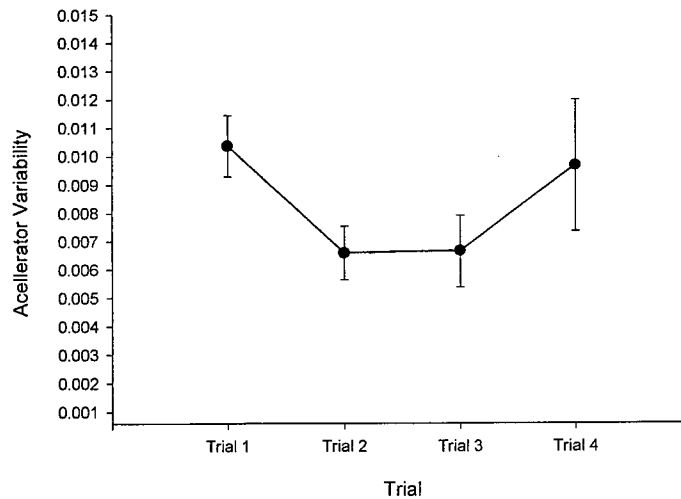


Figure 15. Drivers' accelerator variability as a function of trial order.

### Third and Fourth Condition Analyses

Order effects demonstrated in the previous analyses imply instability in drivers' behavior prior to the third trial. Therefore, measures associated with each subject's third trial and fourth trial were subjected to additional but independent analyses. Because condition order was counterbalanced the third and fourth trial can be analyzed as an independent experiment. In effect, each drivers' first two conditions can be considered practice and the third and fourth trials are treated as a completely between experiments. Global measures were subjected to a completely between ANOVA with factors POLE, SEX, SHRUB, and PAVE. At-point measures were analyzed in a similar manner but included POINTS as a repeated measures variable. In all analyses, three-way and four-way interactions will not be reported because of the low cell sizes associated with the factorial conditions.

Significant caution should be exercised when interpreting these analyses. None of these analyses were planned and most violate at least one major assumption of parametric testing, notably concerning the independence of conditions for between testing.

### Third Condition – Global Measures

Measures of average speed, speed variability, average speed change, lane variability, and accelerator variability were subjected to the analyses indicated above. Analyses for average

speed indicated a significant SEX X SHRUB interaction ( $F(1,16)=4.848$ ,  $p<.05$ , see Figure 16). Analyses for speed change indicated significant main effects for SHRUB ( $F(1,16)=10.009$ ,  $p<.01$ , see Figure 17) and PAVE ( $F(1,16)=4.800$ ,  $p<.05$ , see Figure 18) and a significant POLE X PAVE ( $F(1,16)=4,800$ ,  $p<.05$ , see Figure 19) interaction. Analyses for accelerator variability indicated a significant SEX X PAVE ( $F(1,16)=7.636$ ,  $p<.05$ , see Figure 20) interaction.

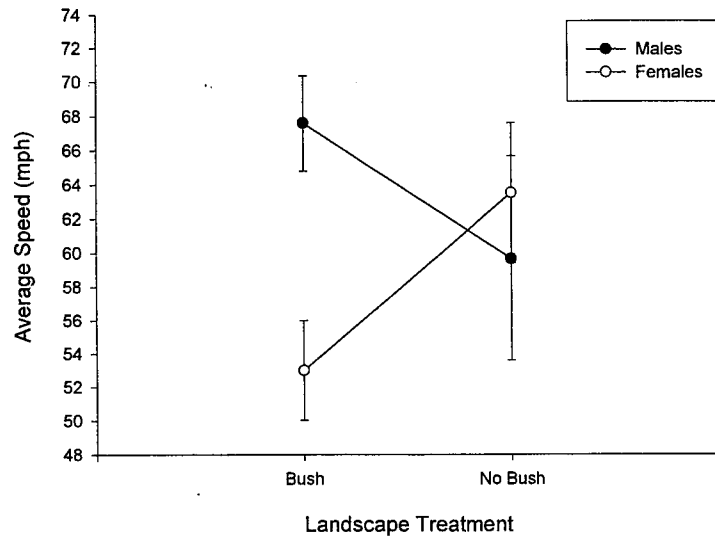


Figure 16. Drivers' average speed as a function of landscape treatment and sex in the third condition.

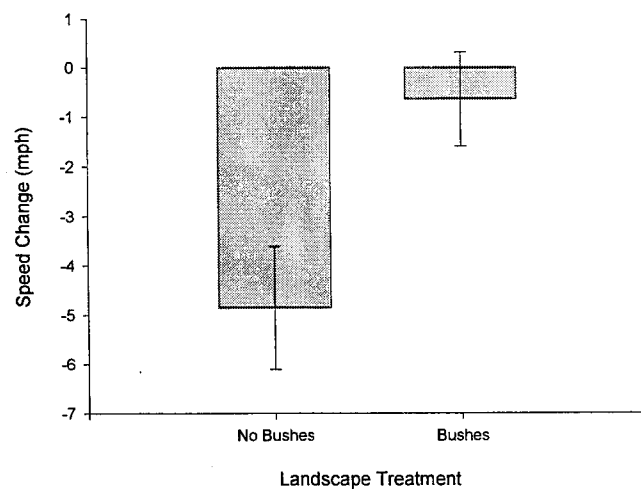


Figure 17. Drivers' average speed change as a function of landscape treatment in the third condition

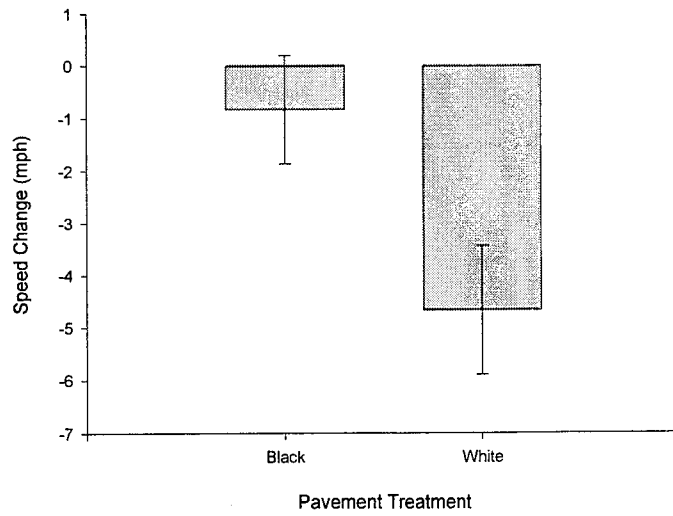


Figure 18. Drivers' average speed change as a function of pavement treatment in the third condition.

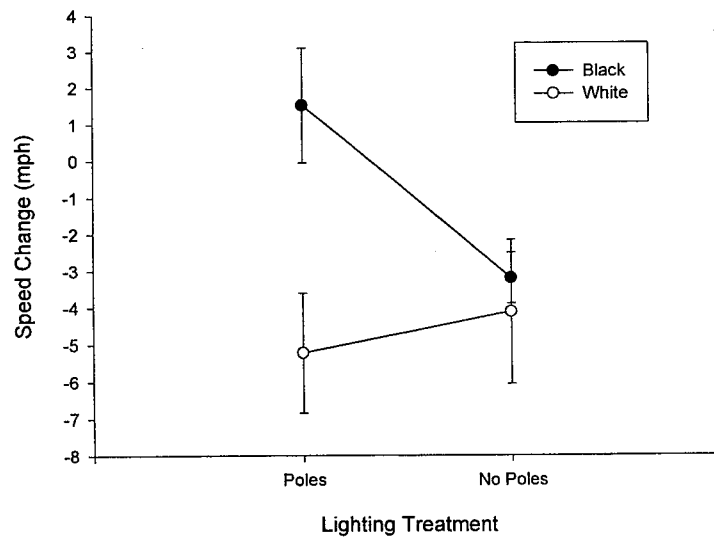


Figure 19. Drivers' average speed change as a function of lighting treatments and pavement treatments in the third condition.

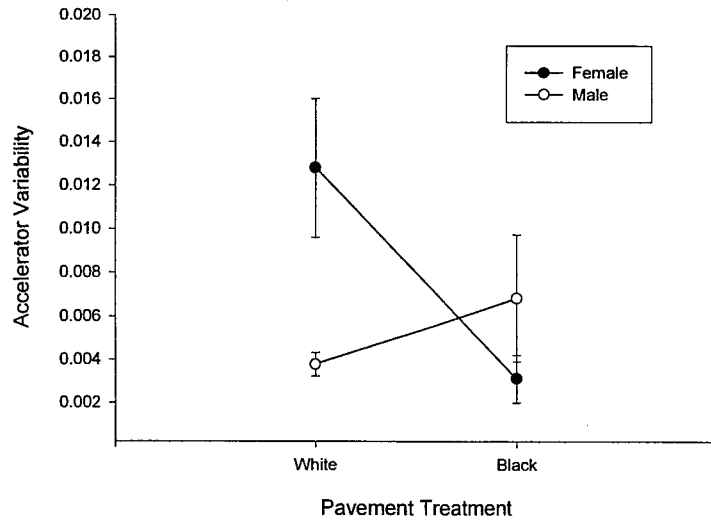


Figure 20. Drivers' accelerator variability as a function of sex and pavement treatments in the third condition.

#### Third Condition – At-Point Measures

At-point measures of speed and speed change were subjected to mixed-model between- (poles, sex, shrubs, and pavement) within (measurement points) ANOVA. Analyses for speed indicated significant main effects for POINT ( $F(5,80)=17.050$ ,  $p<.01$ , not shown) and significant POINT X POLE ( $F(5,80)=2.411$ ,  $p<.05$ , Figure 21), POINT X SHRUB ( $F(5,80)=4.231$ ,  $p<.05$ , Figure 22), and POINT X PAVE ( $F(5,80)=4.243$ ,  $p<.05$ , Figure 23) interactions.

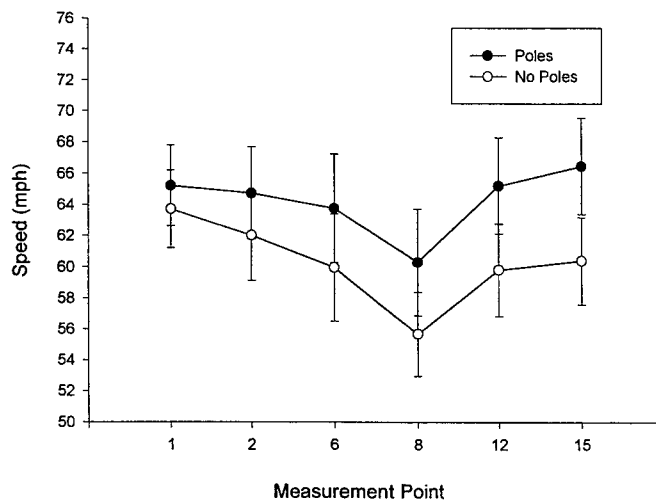


Figure 21. Drivers' speed as a function of lighting treatments and measurement points in the third condition.



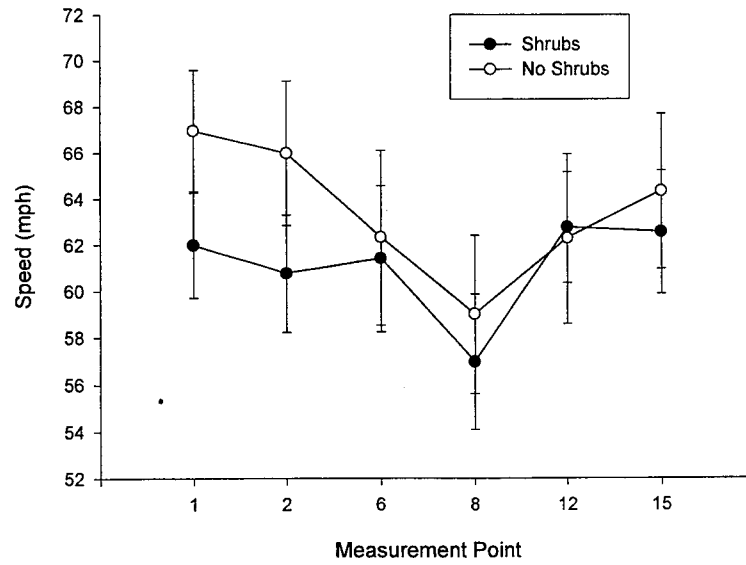


Figure 22. Drivers' speed as a function of landscape treatments and measurement points in the third condition.

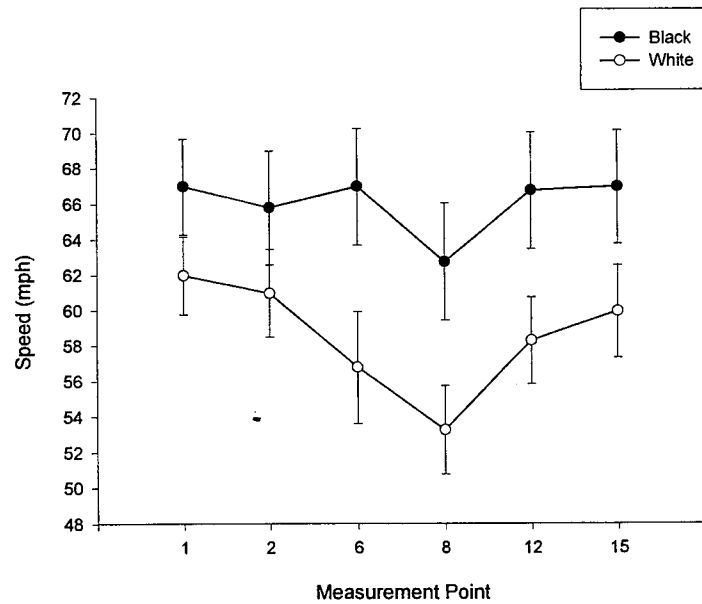


Figure 23. Drivers' speed as a function of pavement treatments and measurement points in the third condition

Analyses for speed change indicated a significant main effect for POINT ( $F(4,64)=16.682$ ,  $p<.01$ , not shown) and significant POINT X SHRUB ( $F(4,64)=3.673$ ,  $p<.01$ , see Figure 24) and POINT X PAVE ( $F(4,64)=3.810$ ,  $p<.01$ , see Figure 25) interactions. There were also significant main effects for POLE ( $F(1,16)=6.129$ ,  $p<.05$ , see Figure 26), SHRUB ( $F(1,16)=6.39$ ,  $p<.05$ , see Figure 27), and PAVE ( $F(1,16)=5.919$ ,  $p<.05$ , see Figure 28) and significant POLE X SEX ( $F(1,16)=5.632$ ,  $p<.05$ , see Figure 29), POLE X PAVE ( $F(1,16)=9.689$ ,  $p<.01$ , see Figure 30), and SEX X SHRUB ( $F(1,16)=7.747$ ,  $p<.05$ , see Figure 31) interactions.

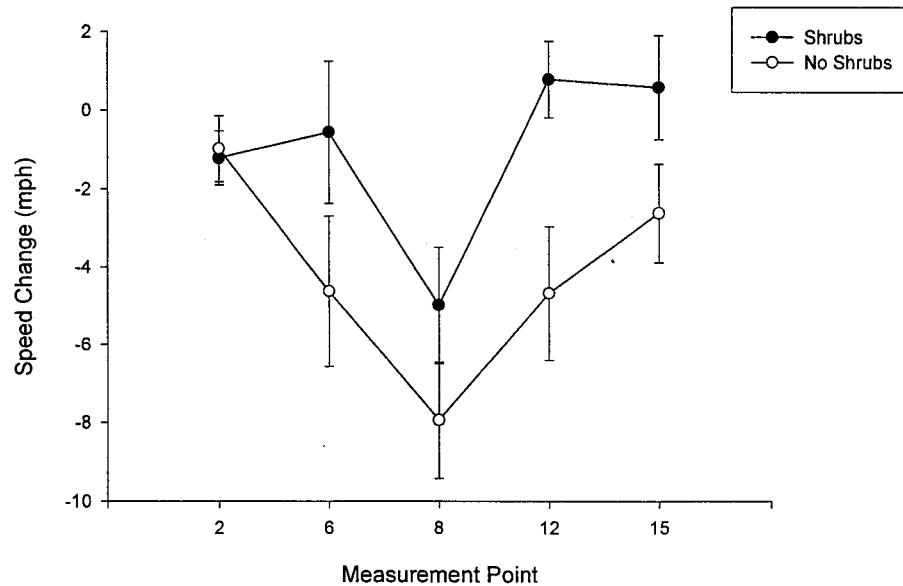


Figure 24. Drivers' speed change as a function of landscape treatments and measurement points in the third condition.

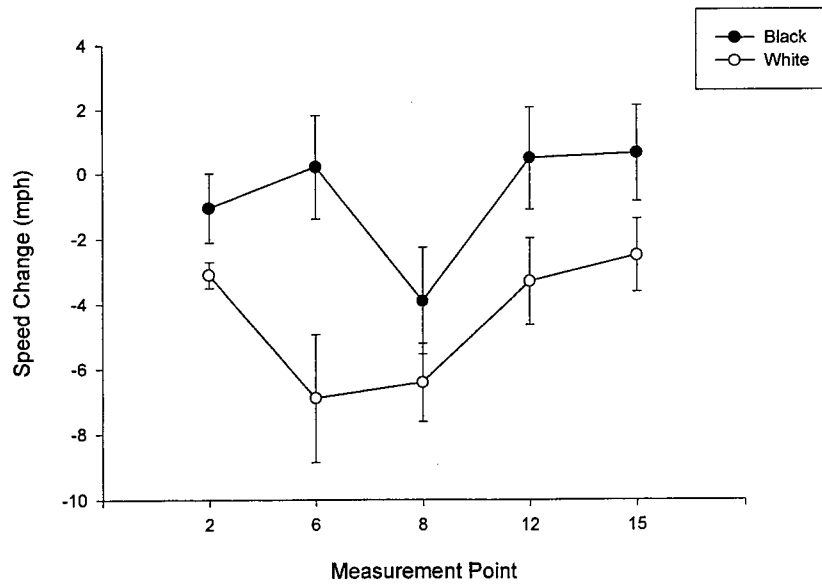


Figure 25. Drivers' speed change as a function pavement treatments and measurement points in the third condition.

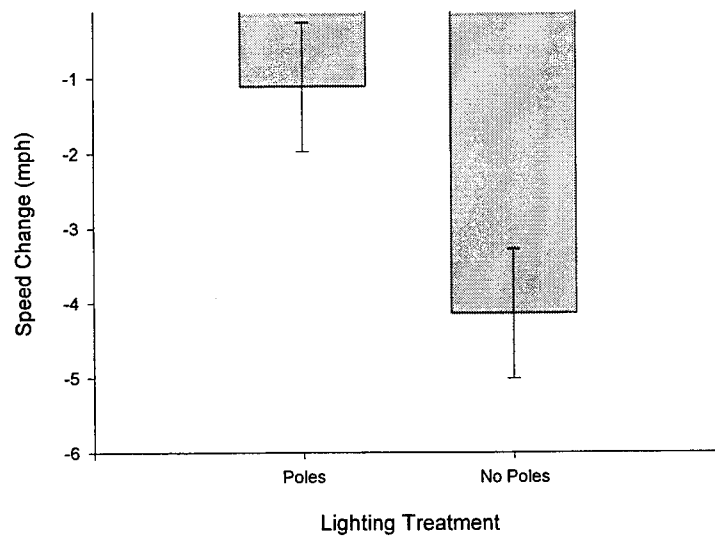


Figure 26. Drivers' speed change as a function of lighting treatments in the third condition.

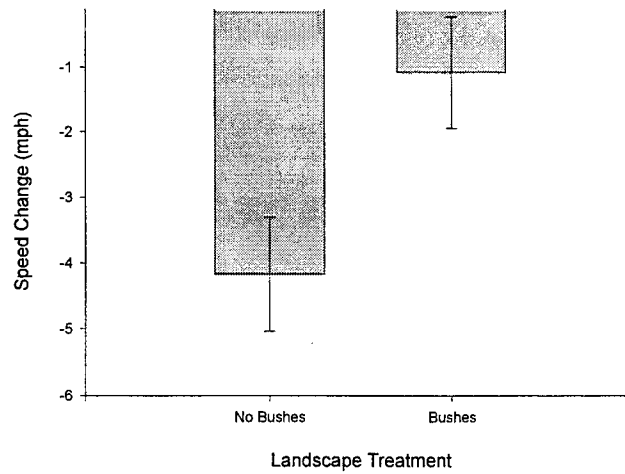


Figure 27. Drivers' speed change as a function of landscape treatments in the third condition.

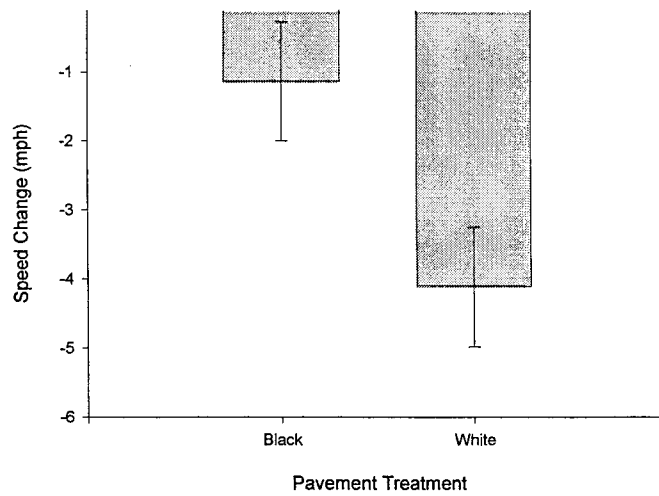


Figure 28. Drivers' speed change as a function pavement treatments in the third condition.

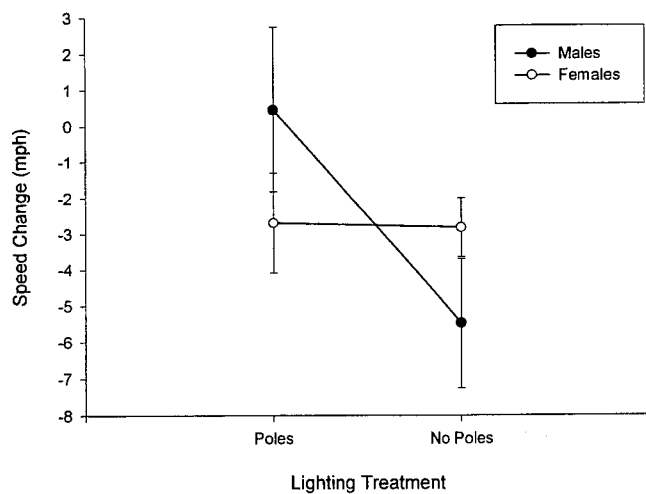


Figure 29. Drivers' speed change as a function of sex and lighting treatments in the third condition.

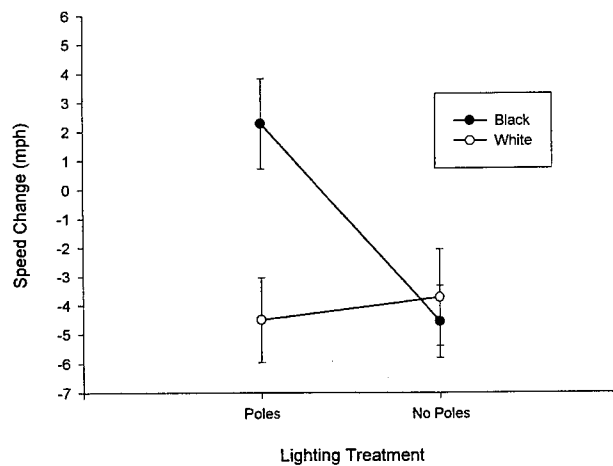


Figure 30. Drivers' speed change as a function of pavement treatments and lighting treatments in the third condition.

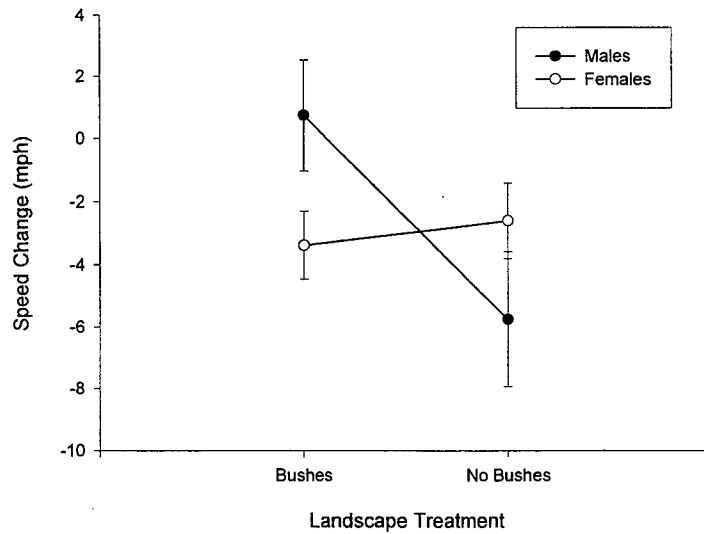


Figure 31. Drivers' speed change as a function of sex and landscape treatments in the third condition.

#### Fourth Condition Analyses

Dependent measures for each subject's fourth condition were analyzed according to the procedures presented in the previous section (Third Condition Analyses). The analyses of fourth condition data was conducted because order analyses indicated stable performance among subjects in the fourth condition.

#### Fourth Condition-Global Measures

Measures of average speed, speed variability, average speed change, lane variability, and accelerator variability were subjected to the analyses indicated in the previous section. Analyses for average speed change indicated a significant main effect for SHRUB ( $F(1,16)=5.726$ ,  $p<.05$ , see Figure 32).

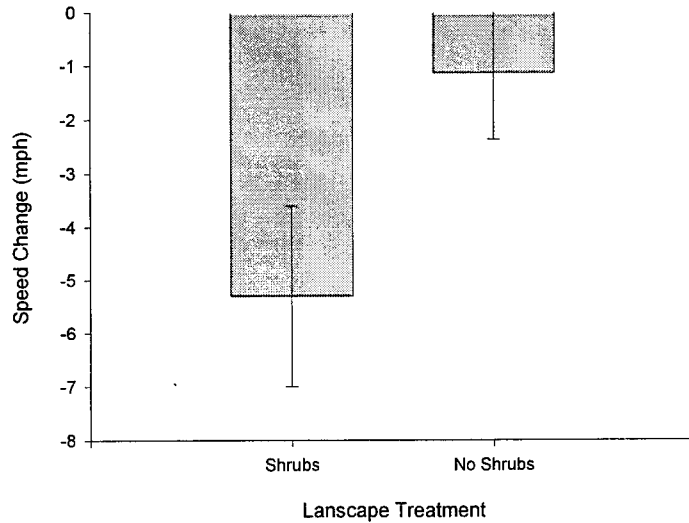


Figure 32. Drivers' average speed change as a function of landscape treatments in the fourth condition

At-point measures of speed and speed change were subjected to mixed-model between- (poles, sex, shrubs, and pavement) within (measurement points) ANOVA. Analyses for speed indicated a significant main effect for POINT ( $F(5,80)=15.314$ ,  $p<.01$ , not shown) and significant POINT X SHRUB ( $F(5, 80)=4.317$ ,  $P<.01$ , see Figure 33) and POLE X BUSH ( $1,16)=5.102$ ,  $p<.05$ , see Figure 34) interactions.

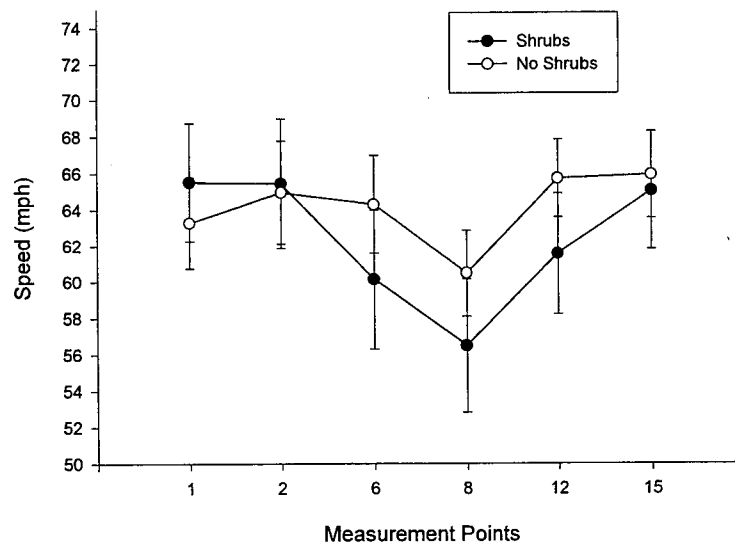


Figure 33. Drivers' speed as a function of landscape treatments and measurement points in the fourth condition.

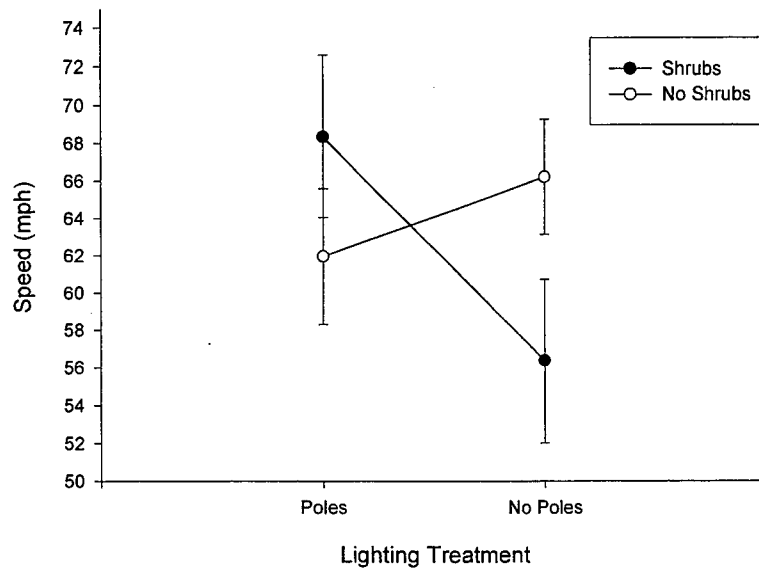


Figure 34. Drivers' speed as a function of landscape treatments and lighting treatments in the fourth condition.

Analyses for speed change indicated significant main effects for POINT ( $F(4, 64)=21.931$ ,  $p<.01$ , not shown) and SHRUBS ( $F(1,16)=6.397$ ,  $p<.05$ , see Figure 35) and a POINT X SHRUB ( $F(4, 64)=3.269$ ,  $p<.05$ , see Figure 36) interaction.

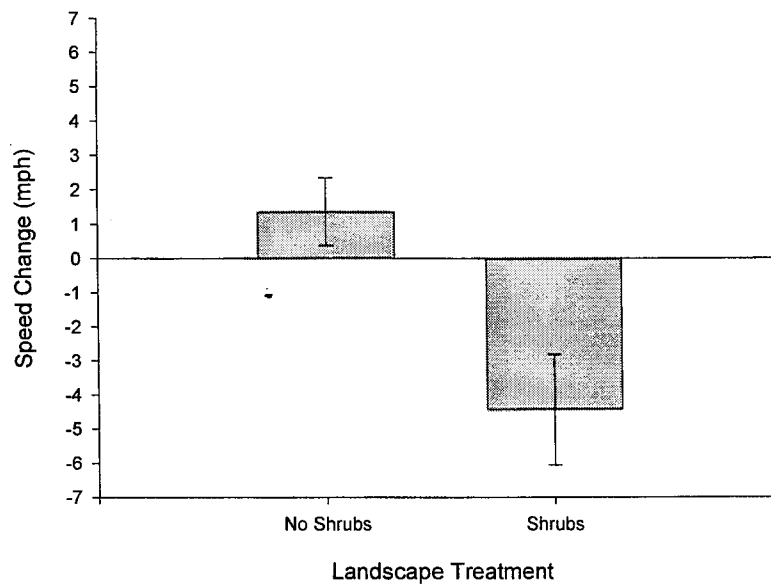


Figure 35. Drivers' speed change as a function of landscape treatments in the fourth condition.



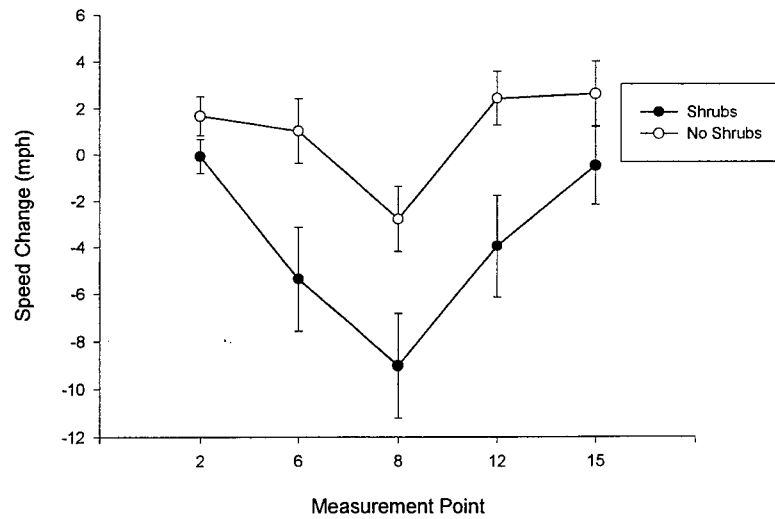


Figure 36. Drivers' speed change as a function of landscape treatments and measurement points in the fourth condition.

#### Subjective Debrief Questionnaire

Each subject was asked to respond to a debrief questionnaire designed to elicit responses concerning driving habits, perception of the simulator and simulator controls, perception of design elements in the conditions, and perception of their own behavior and performance in the experimental trials. Question formats were designed to elicit both specific and general information through a combination of likert-type, forced choice, and open-ended questions. All 32 subjects responded to the questionnaire, although some subjects chose not to answer some questions. A summary of questionnaire responses is detailed in Table 5.

TABLE 5. SUMMARY OF DRIVERS' RESPONSES TO THE DEBRIEF QUESTIONNAIRE

#### DRIVER INFORMATION

1. Age: mean = 27.4 years range = 19-57 years
2. Sex: males=16 female=16
3. Do you have a valid drivers' license? Yes=32

	<u>Mean</u>
4. IN WHAT YEAR DID YOU OBTAIN YOUR DRIVERS' LICENSE?	
1988	
5. How often do you drive? (very frequently 1 – 5 almost never)	1.5
6. How much of your driving occurs: (all 1 – 5 none)	
on city streets?	2.2
on rural/country roads?	3.8
on highways?	2.3
7. How often do you: (always 1 – 5 never)	
KNOW the posted speed limit?	2.0
KNOWINGLY drive faster than the posted limit?	2.1
8. Do you have any other comments concerning your driving habits? (paraphrased)	
• I am quite aware of children and older people in the environment, I try to anticipate their actions, as well as street crossings and signage	
• I slow down in areas where I suspect more traffic	
• I am a frequent speeder	
• I'm a pretty safe driver	
• Most of my driving is on highways, I often fluctuate speeds going in and out of towns, I always drive over the speed limit and don't want to get pulled over.	
• With other cars around, I tend to drive slower. I driver very slow when there are many cars and people around.	
• Driving sometimes makes me tired	

#### Simulator and Simulator Controls

9. I felt nausea (none 1 – 5 much)	2.3
10. I felt: (always 1 – 5 never)	
in complete control of the steering	2.3
in complete control of the gas	2.1
in complete control of the brake	2.6
comfortable in the car	2.6

#### Trial/Condition Information

11. In the experimental trials: (always 1 – 5 never)				
I focused on the speedometer to control my speed				2.5
I drove at a speed that was comfortable				1.8
I consciously made an effort to change my speed				2.7
12. If so, which city section(s)?				
Pre (14)	Early (18)	Mid (9)	Late(4)	Post (11)

13. I unconsciously changed my speed (always 1 – 5 never) 3.2
14. If so, which section(s)?  
Pre (10) Early (11) Mid (10) Late(10) Post (7)
15. Was there a particular part of the trial where you noticed changes in your speed?  
Yes 27 No 5
16. If yes, which section(s)?  
Pre (10) Early (9) Mid (13) Late(5) Post (5)
17. Was there a part of the trial were it was difficult to maintain the target lane position?  
Yes 23 No 9
18. If so, which section(s)?  
Pre (12) Early (9) Mid (11) Late(5) Post (5)
19. Did you notice bushes in some trials?  
Yes 28 No 4
20. Did you change your speed because of the bushes?  
Yes 12 No 20
21. If so did you:  
Increase? 0 Decrease? 12
22. Did you notice the road change colors between trials?  
Yes 13 No 18
23. Did you drive faster with:  
Black Shoulders? 21 White Shoulders? 6
24. Were there light poles along side the road?  
Yes 16 No 15
25. If so, do you think the poles affected your speed?  
Yes 6 No 17
26. Did your speed:  
Increase? 3 Decrease? 6
27. You drove through the city four times. Did your driving changed between the four trials?  
Yes 31 No 1
28. Why do you think your driving changed? (truncated)
- Got more used to it, knew what was coming up
  - I had better control of the car, knew what to expect, looked around more
  - More familiar with city, saw design elements
  - Became more familiar with area, became more comfortable driving it
  - Drove slower through the city than I normally would
  - Became comfortable and familiar
  - Knew where turns were, became more comfortable with simulator
  - Speed increased because I knew nothing would jump in front of car
  - Didn't decrease through city as much
  - Became more comfortable with apparatus, anticipated environment
  - Knew roadway
  - Drove always like highway because no pedestrians or other traffic
  - Knew what to expect in city
  - At first cautious, then not cautious

- Got used to scenery and which speed suited road conditions
- Increased speed in straight sections
- Became comfortable with city, thus increased speed.
- Got a feel for roads and scenery , when faster as I remembered streets

29. Do you have any other comments? (truncated)

- I slowed down in relation to the green hedge and the white and gray color on the medians
- Appeared to be blurry and brightness/darkness unreal
- Inside of car was warm
- Bushes in center made me feel like slowing down
- Speed increased with each trial, became more aware and used to simulation, I normally would have decreased speed pre-city and coasted in
- It was most interesting

## DISCUSSION

### VISUALIZATION

Visualizing and interacting with the planned roadway design produced numerous benefits, including increased communication between team members, increased communication between state agencies, rapid problem identification, rapid problem resolution development, efficient design development, and effective design development. Some of these benefits resulted in actual changes to the planned project. Examples of changes made as a result of visualization:

- The original proposal to use white paving in the center left turn lane was changed to using white paving on the shoulders as well.
- The original proposal to use trees near the roadway was changed to taller shrubs. The taller trees with trunks did not create a feeling of constriction from the driver's point of view. Trunk sizes were also too large for the designed proximity. The length of shrub treatments was also extended.
- Shrubs were placed on the median once it was recognized that they would have a major visual impact resulting in a greater feeling of constriction.
- The use of light poles as an influence on driving speed emerged as an option to be explored even though it was not considered a traffic calming strategy in the original proposed design.

Considerable discussion was devoted to the need for greater detail and realism in the model. Initial models represented the road as flat and represented a few general features of the roadside such as familiar buildings. To simply test the influence of the traffic calming strategies, this level of visualization would have been sufficient. The Mn/DOT team, however, urged the University team to add realistic grade changes and as much detail as possible in the form of buildings, driveways, cars, signs, mailboxes, people, etc. Some details simply cannot be done at the resolution of the current simulator system (this can be improved with additional computer power). Other features such as the noticeable grade changes made the team feel that they were

working with an accurate, representative model - not a simplified abstraction. This desire for realism emphasizes the value of this project as a visualization tool, not just a research tool.

## EXPERIMENTATION

Seven key questions were developed concerning the experimentation data presented in this report. Some questions were developed in response to specific Mn/DOT needs related to the target reconstruction project. Other questions were developed to clarify and elaborate on selected methods, analyses, and data summaries.

*Were there any factors related to the subjects that contributed to the results?*

Subjects in the experiment, on average, were 27.4 years of age, had been driving for almost 10 years, drove relatively frequently, drove frequently on city streets and highways, and knew the posted speed limit but usually drove faster. Subjects are thought to over-represent younger drivers (few older drivers were tested) and represented only private vehicle drivers (no commercial drivers were tested).

Most subjects reported some level of simulator induced sickness (i.e., nausea). This effect is common among simulator experiments and the reported level was not judged to be significant. A reasonable level of control for steering, gas, and brake controls was reported and subjects reported a reasonable level of comfort in the vehicle. In general, subjects behaved consistently with the provided instructions, reporting reasonable levels of speedometer use and compliance with instructions to drive at a 'comfortable' speed.

Few effects were demonstrated for driver sex with males possibly more susceptible to environmental manipulations (see Figures 29 and 31). However, some data refute this hypothesis (see Figure 16).

*Why was a trial order analysis conducted?*

Debrief questionnaires indicated thirty-one subjects reported changes in behavior over the course of the four experimental trials. When prompted for a reason, 24 subjects reported a

noticeable increase in comfort, with descriptors such as 'accustomed', 'familiar', and 'used to' employed frequently. Despite a formal training protocol and practice sessions, it appeared that drivers' behavior was influenced as a function of exposure to the simulator. While an increase in perceived comfort is common, perceived change in behavior is undesirable and could adversely effect patterns of behavior associated with the experimental conditions. Another possibility is the occurrence of multiple-treatment interference which can occur when the same subjects are exposed to more than one level of the treatment. Based on these data and observations, a decision was made to examine the influence of exposure (across trial order) on general driving behavior, independent of the influence of the experimental factors under manipulation.

*What is the significance of the order analyses?*

The order analysis (see Figures 13, 14, and 15) indicated marked changes in driver behavior after the first trial. Subjects drove faster, with less speed variability, and worked the accelerator more moderately after the first and, in some instances, after the second trial. In general, subjects appeared hypersensitive in the first trials, perhaps as a function of their expectations concerning desirable behavior. Subjects drove slower (perhaps more cautiously) and were more apt to change speeds in earlier trials. As they were exposed to more trials, many subjects reported they drove faster because they knew what to expect (i.e., knew what was coming up in the model). In essence, subjects' behavior was more consistent and more stable after the second trial. These data are consistent with subjective reports of increased comfort in later trials. It should be noted that order effects were not related to any between subject factor and thus can be considered independent of experimental factors under manipulation.

Problems related to trial order pose significant constraints on the planned analyses. Variability produced by exposure time in the simulator limit the power of the parametric analyses to identify patterns of behavior. Where patterns of behavior were consistent (e.g., pavement treatment manipulation) one can be confident as to the predictability of drivers' behavior. However, where patterns were not evident (e.g., landscape treatment) a definitive conclusion is difficult because effects may have occurred, but simply varied too widely to facilitate predictability.

Data indicating the stability of driver performance in trials 3 and 4 form the basis for the unplanned post-hoc analyses. Driver performance, characterized by high rates of speed and low susceptibility to environmental characteristics, are not uncommon in the target section of TH61 through Tofte, MN. Thus, by the end of the experimental trials, subjects' behavior in the experiment was characteristic of drivers behavior in the actual environment. Therefore, despite the post-hoc nature of the analyses, data in later trials is expected to have an acceptable level of generalizability. Nevertheless, unplanned analyses of data subsets should be viewed with some caution.

*Was the presence of lighting poles an effective speed calming device?*

Planned and unplanned analyses indicate that the presence of light poles did not significantly contribute to more moderate speeds or speed reduction. In fact, in some cases, the presence of poles, in combination with other factors (see Figures 7, 12, 18, 21, 26, 29, and 30), reduced the potential for speed control and reduction. In many instances, the presence of poles offset the potential benefits of the white pavement treatments.

It was anticipated that the strong vertical component associated with the lighting poles would provide salient speed cues, stimulating drivers to check or reduce speed. Why was the anticipated effect for lighting poles not achieved? There are a number of potential explanations. First, the benefits of vertical elements as speed cues may be overstated. Of the 16 subjects who received poles, only 6 reported poles effected speed, and only 3 of these respondents reported speed reduction. Second, the salience of the vertical cue may be reduced by the abrupt change in visual scenery in the town. In essence, subjects failed to attend to the poles and were distracted by visual scenery. Third, pole placement (road proximity) and pole spacing may not have been optimized for effect. Perhaps larger poles, closer together, might have been effective. Finally, speed control benefits for poles may require repeated exposure over long distances. Given the short distance through the city (approximately 3 km), effects for the presence of poles may not have had time to accumulate.



### *Were landscape treatments an effective speed calming device?*

Despite some demonstrated benefits for the presence of landscape treatments (see Figures 22, 28, 33, 35, and 36), results varied widely (see Figures 17, 24, and 27). Moreover, landscape treatment effects were only detected in post-hoc analyses of trials 3 and 4. No effects were detected in the complete data set, although this is probably due to the fact that behavior related to landscape treatments *did* vary so widely from trial to trial. Thus, landscape treatments indeed had an effect on driver behavior, but the effect was markedly inconsistent.

Therefore, under some circumstances, the presence of landscape treatments can be considered effective traffic calming devices. Data in the present report supports a recommendation for further research in this technique. These conclusion are based on the following arguments. First, shrubs and bushes, as traffic calming devices eventually were effective (i.e., fourth condition). Perhaps repeated exposure is required before desirable effects are achieved. Second, desirable effects for landscape treatments may have been discrete (i.e., specific to the areas in which the shrubs were planted), a problem magnified by the relatively short length of the treated areas and the high rates of speed. Third, the potential magnitude of benefits, especially for speed change, are too great to ignore. Benefits for landscape treatments in the fourth trial were in excess of 5 mph. Fourth, landscape treatments were salient, with 42.8% of subjects reporting conscious speed reduction in response to the treatments. Finally, while the visual aspects of the treatments were reproduced (i.e., the visual image of the shrubs) the physical characteristics of the treatments (e.g., proximity to the vehicle) could not be accurately reproduced in the simulator. The closest the images got to the vehicle were approximately 6 ft, the distance from the vehicle to the projection screen. Thus, the physical constriction planned for in the design could be reproduced in the simulation. Therefore, it is likely that the potential for success in the real-world is greater than demonstrated by the simulation.

### *Were colored pavements an effective traffic calming device?*

White pavement treatments were reliably and consistently related to more moderate speeds and larger speed reductions (see Figures 10, 11, 18, 19, 23, 25, 28, and 30). In particular, analyses on the complete data set (see Figures 10 and 11 ) indicated benefits for white pavement.

However, effects appear to be contingent on substantial exposure as benefits for white pavement treatments were not prevalent until later in the model (point 8). Moreover, the magnitude of effect is relatively small, approximately 2 mph for speed and speed change. However, by the third trial both magnitude and onset of effect increased dramatically (see Figures 18, 23, 25, and 28) with differences, in some cases, in excess of 5 mph. Strangely, only 13 subjects reported they noticed changes in the road coloring, although 21 subjects reported they drove faster, in general, with black shoulders.

*Were there any significant speed or speed change patterns through the city?*

There was a reliable pattern of speed independent of any of the design factors. That is, the speed pattern identified was demonstrated regardless of the specific combination of design elements in any particular condition. Significant speed and speed change patterns were remarkably consistent and reliable in all data analyses (i.e., effects for measurement POINT). In fact, many were not graphically presented due to redundancy. It was anticipated that speed data would reveal few effects, principally due to the variability in speeds produced by letting subjects drive at any speed they felt 'comfortable and in control'. Although variability in speeds was demonstrated, effects were still common. Speed change measures, based on drivers' individual speed at the town entry, were designed to control for individual differences and can be considered to be a principle measure of interest, because all treatments were designed to slow or calm speeds.

The speed and speed change profiles displayed in Figures 8 and 9 will be discussed because they contain the most measurement points, 15 and 14, respectively. However, these patterns should be considered representative of all main effects for measurement POINT reported in other analyses.

In summary, the profiles indicate (distance from entry sign, see Table 3):

- Dramatic speed reduction right after the welcome sign (first 169meters)
- Relatively consistent speed from 169 m to 621 m

- Maximum speed reduction by 1009 m, about 7 mph in total
- Dramatic speed increase from 1009 m to 1788 m
- Slight speed increase from 1788 m until the town exit (the last measurement point).

Based on the demonstrated speed and speed change patterns the following observations are presented:

- In general, the planned design contributed to early and marked speed reduction. In this sense, the designed entry gateway was effective.
- Despite a downhill change in grade after the entry gateway, vehicle speeds reduced, indicating overt action on the part of the drivers to slow down.
- Speed reduction 'bottomed out' approximately at the bottom of the downhill. These data are consistent debrief reports indicating conscious speed reduction associated with 'Pre', 'Early', and 'Mid' sections of the town.
- Speed increases after the bottom of the hill should be considered a significant safety hazard, principally because vehicles are more than 1200 meters from the end of the town. These data are remarkable because of the magnitude of speed change and because the increases occurred in spite of the uphill grade. Drivers' overcompensated for the hill by overtly and dramatically increasing speed. Perhaps drivers' perception of risk decreased because of the reduction in the number of buildings and landmarks after the bottom of the hill. Nevertheless, the high rates of speed in the latter sections of town, coupled with drivers' willingness to increase speed in this area, signal a potential safety threat for both vehicle and pedestrian traffic.



## **CONCLUSIONS**

### **VISUALIZATION**

- High-fidelity visualization can be achieved from available resources within Mn/DOT (Human Factors Research Laboratory, engineering cross sections, photo surveys, architectural plans).
- Visualization contributed to increased communication among team members and state agencies.
- Visualization facilitated problem identification and resolution strategy development.
- Visualization 'drives' of potential design scenarios contributed to effective design by highlighting spatial and timing aspects of design elements.
- Visualization contributed to efficient design development through rapid prototyping of potential design elements.
- Visualization facilitated decision making concerning potential design options and design elements.

### **EXPERIMENTATION-GENERAL**

- Experimentation is an effective means to evaluate roadway design options
- Methodologies for this type of experimentation will need to evolve in order to produce reliable and meaningful data on which to make design decisions.
- Early trials were characterized by higher rates of speed and greater speed variability indicating instability of behavior. These undesirable effects contributed to considerable variability in the data and constrained the power of the planned analyses. In response to this problem, additional analyses were performed (post-hoc testing) on drivers' data in the third

and fourth condition in an attempt to draw conclusions on stable performance. Due to methodological constraints, data from these analyses should be interpreted with caution.

- Understanding driver behavior and performance was facilitated by repeated measurements through the entire town. Many global measures of behavior were not sensitive to experimental manipulations. This is probably due to the variability of speeds through the town as drivers both slowed down and sped up considerably. Changes in elevation in the town probably contributed to some of this effect.

## **EXPERIMENTATION-SPECIFIC**

- Speed and speed change profiles indicated a pattern of behavior characterized by a marked decrease in speed early in the town, followed by 500 m of steady speed, then a marked decrease in speed until the bottom of the hill. On the upgrade speed increased dramatically, evening off toward the end of town. It is not clear what contributes to the significant increase in speed on the upgrade, especially as drivers are travelling uphill.
- Speed reduction ‘bottomed out’ approximately 1000 m into the town, an average speed reduction of approximately 7 mph.
- Drivers’ consciously slowed vehicle speeds entering the city and consciously increased vehicle speeds in the last 1200 meters of the drive. These latter data indicate a potential safety hazard.
- Gateway/entry design is effective, contributing to early and marked speed reduction.

## **PAVEMENT TREATMENTS**

- White pavement treatments contributed to lower and more moderate speeds than standard black pavement treatments.

- Effects for white pavement were evident in many analyses (reliable) and always indicated benefits for the white treatment (consistent). However, in many cases, benefits were only evident after some exposure to white pavement (later in the city). In other instances, the magnitude of difference was statistically significant but small.
- Certain combinations of other design elements and factors (e.g., sex) with pavement treatments appeared to produce conditions associated with undesirable behavior. In general, data indicated undesirable effects associated with standard black pavement
- 66% of subjects reported driving faster with standard black pavement.

## **LIGHTING TREATMENTS**

- Data did not support the presence of light poles as a major contributor to moderate speeds or speed reduction. In fact, the presence of light poles, as a major factor, or in combination with other factors in the experiment, often reduced the potential for speed control and reduction.
- In some circumstances, the presence of lighting poles offset the potential benefits of the white pavement treatments.

## **LANDSCAPE TREATMENTS**

- Results for the presence or absence of landscape treatments varied too widely to support a definitive conclusion.
- The inability to accurately create physical characteristics of the landscape treatments in simulation constrained the overall effect for these design elements in the experiment. Thus, it is likely that landscape elements implemented in the real world would have greater potential for success than that demonstrated in the present simulation and experimentation.

- Under some circumstances, the presence of landscape treatments can be effective traffic calming devices. However, more research is required before these exact circumstances can be identified and reliably implemented.
- In those circumstances where landscape treatments were effective, the magnitude of speed reduction benefit was significant.
- 42.8% of subjects reported conscious speed reduction in response to the presence of landscape treatments.



## **RECOMMENDATIONS**

### **VISUALIZATION**

- Use computer visualization as part of the roadway and environmental design process. Visualization enhances communication and contributes to effective and efficient design.
- Use visualization to develop and interact with potential designs. Interaction (e.g., drive through) provides important insights that contribute to the subjective evaluation of designs.
- Use visualization to identify potential design problems and develop resolution strategies.
- Where possible, attempt to clarify the purpose and audience for the visualization/simulation work. For example, a public presentation, a design team work session, and a human factors research experiment all have different requirements, and degrees of realism required.
- Continue to expand applications for advanced simulation. For example, the Human Factors Research Laboratory can produce video tapes of designs that can be distributed to team members in remote locations.
- Continue to identify Mn/DOT projects which may benefit from advanced simulation. However, not all design project are suited for interactive driving simulation.

### **EXPERIMENTATION**

- Consider the designed gateway as effective in producing speed reduction in drivers
- Implement white pavement treatments in the town as a speed control and speed reduction strategy. However, expect that noticeable effects may not occur until later in the town.
- Do not implement lighting poles as a speed reduction or moderation strategy.
- Consider landscape architecture as potential speed control devices.

- Develop a plan to monitor driver behavior in the field subsequent to the completion of the reconstruction project. Monitoring drivers' behavior in the field will ultimately refine and validate visualization and experimentation research programs.